Analysis of Data From TCS-08

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LONG-TERM GOALS

The long-term goals of this project are to understand better the mechanisms operative in tropical cyclogenesis and to transfer this knowledge to large-scale models in order to improve forecasts of tropical storm formation. Since convection constitutes the biggest uncertainty in this process, our focus is to understand how convection affects and is affected by cyclone-scale flows.

OBJECTIVES

Our objective in this segment of the program was to use our vorticity and thermodynamic analyses of developing and non-developing tropical cyclones to understand better the process of tropical cyclogenesis. In addition to results from TCS-08, we have added results from ITOP and the NSF-funded PREDICT project.

APPROACH

The TCS-08, ITOP, and PREDICT field programs provided a rich set of data including Eldora radar data (TCS-08) and dropsondes (all projects) from a variety of platforms. We have analyzed the data from all three of these projects, focusing on the production of the three-dimensional variational analyses (3D-VAR) of winds and thermodynamic data for all potential cyclogenesis cases. From these analyses, we have developed a coherent picture of the mechanisms underlying tropical cyclogenesis.

WORK COMPLETED

Graduate student Saška Gjorgjievska has finished and written up the diagnostic analysis of about two dozen tropical cyclogenesis missions from the TCS-08 and PREDICT field programs. Our vorticity analysis scheme of dropsonde and airborne Doppler radar data allowed her to extract the strength of the low-level and mid-level circulations in these cases, as well the circulation tendencies at each level. The balanced response to such a circulation is the development of a warm anomaly

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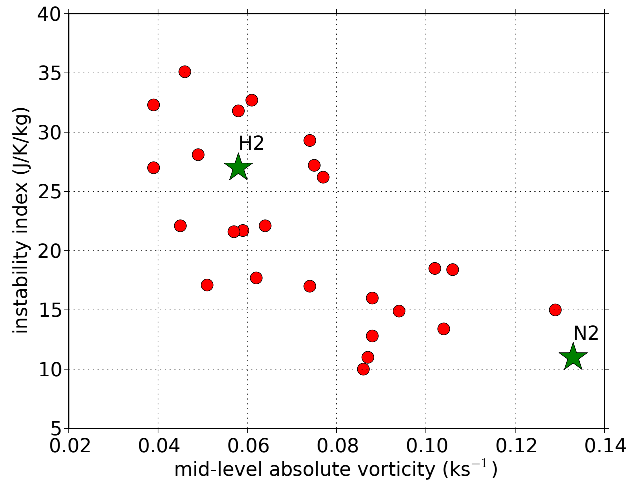

Figure 1: **Instability index vs. mean mid-level absolute vorticity for tropical cyclogenesis missions flown during TCS-08 and PREDICT. H2 and N2 indicate respectively a non-developing (Hagupit2) and a rapidly developing tropical disturbance (Nuri2).**

above the circulation maximum and a cold anomaly below. We characterized the development of these virtual temperature anomalies by an "instablity index"

$$I = s^*(low) - s^*(mid)$$

where s^* is the saturated moist entropy, "low" indicates a disturbance-wide average over $1-3$ km, and "mid" indicates an average over $5-7$ km. Smaller instability index corresponds to a stronger warm-cold dipole of this type. Figure 1 shows that low instability index is correlated with strong mid-level vorticity, a result that would be expected if the temperature dipole is indeed a balanced response to convection and not, for instance, an unbalanced response to the convection.

The significance of instability index is its influence on convective mass fluxes. High instability index results in top-heavy vertical mass fluxes, as indicated in the example of Hagupit2 (H2 in figure1) in figure 2. Hagupit eventually intensified into a typhoon, but at the time of observation was a non-developing tropical wave. In contrast, Nuri2 (N2 in figure 1) was intensifying rapidly when observed and as figure 2 shows, its mass flux profile is bottom-heavy. The other cases in our sample behaved similarly. Levels at which the mass flux increases with height exhibit mass and vorticity convergence, resulting in increasing circulation with time, whereas decreasing mass flux with height shows the reverse. Thus an environment with high instability index results in the spinup of a mid-level vortex, whereas low instability index causes a low-level vortex to form and intensify. Figure 3 verifies this result for our data set.

One loose end is the plausible but unproven assertion that the temperature dipole observed in conjunction with a mid-level vortex is a balanced response to the vortex. To address this question, Raymond applied a non-linear balance potential vorticity inversion code (Raymond 1992) to an axisymmetric idealization of the observed potential vorticity distributions in two TCS-08 cases, Nuri1 and Nuri2. The upper panels of figure 4 show the observed and assumed potential vorticity profiles averaged over the two cases, while the lower panel shows the actual virtual potential temperature profiles and the profiles reconstructed from the potential vorticity inversion. The

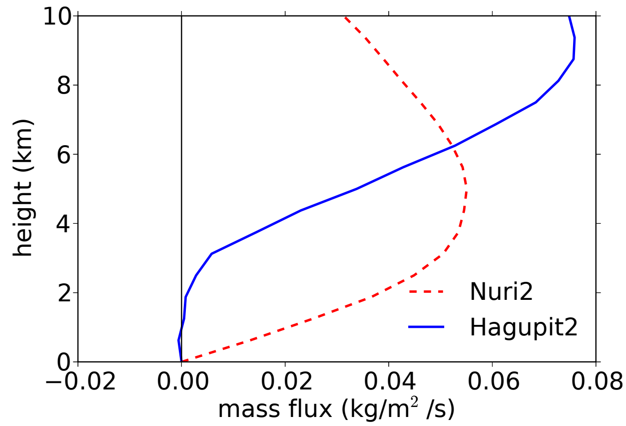

Figure 2: **Vertical mass flux profiles for the Nuri2 and Hagupit2 tropical cyclogenesis cases. Nuri2 was intensifying, Hagupit2 was not.**

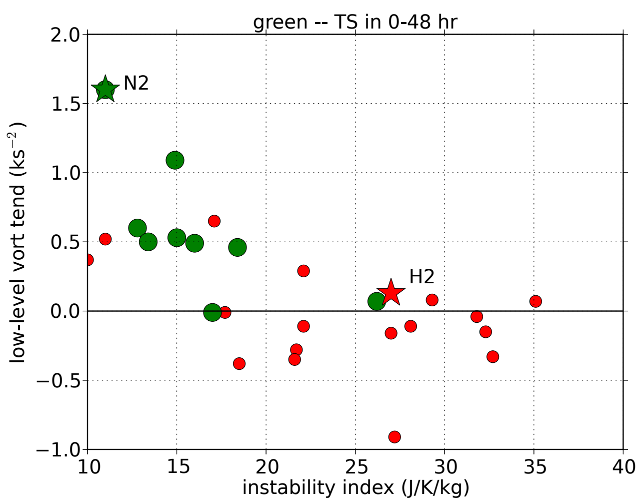

Figure 3: **Low-level vorticity tendency vs. instability index. Large green symbols indicate spinup into a tropical storm within** 48 **hr of the observation.**

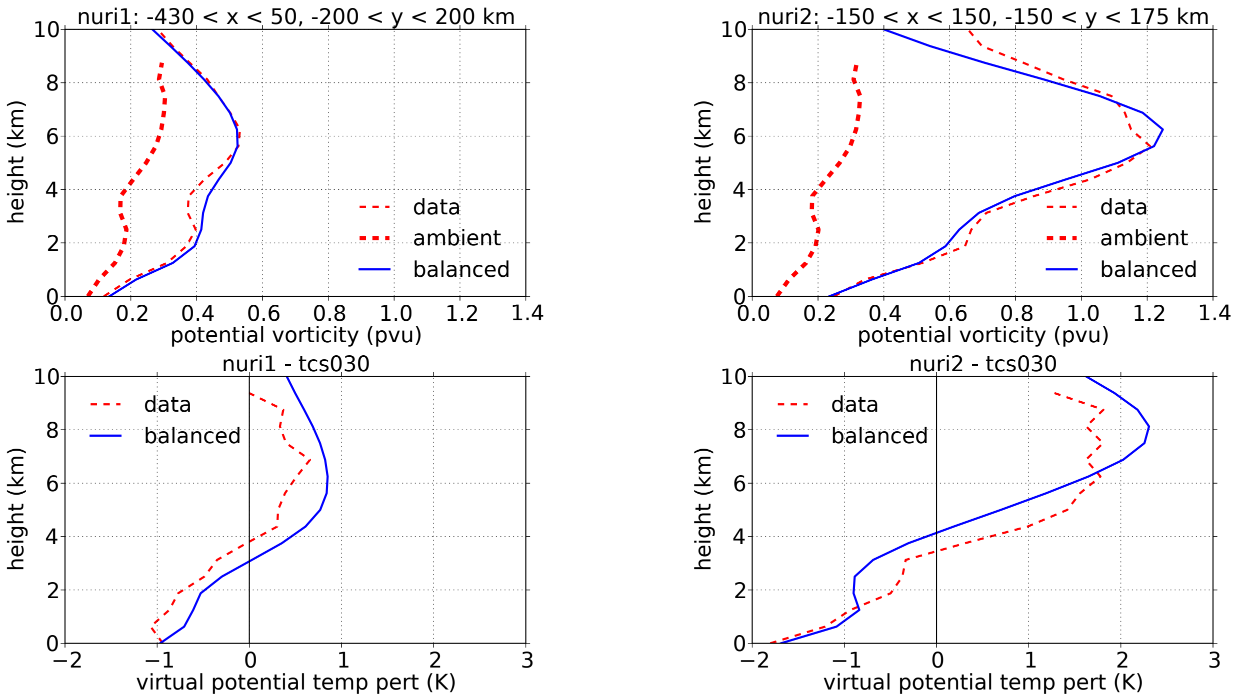

Figure 4: **Horizontally averaged potential vorticity (upper panel) and virtual potential temperature perturbation (lower panel) for Nuri1 (left) and Nuri2 (right). The thick dashed red line in the upper panel represents the ambient potential vorticity, while the thinner dashed red lines represent areally averaged observations in both panels. The solid blue lines show the averages over a corresponding region in the balanced model result.**

agreement between the actual and reconstructed profiles is reasonably good, providing evidence that the balance assumption is reasonably valid in these cases.

Graduate student Ana Juračić is computing the moist entropy budget of intensifying and mature tropical cyclones using our 3D-VAR analyses. She has added the ITOP observations to our catalog of tropical cyclogenesis cases. Ordinary tropical convection tends to export moist entropy laterally. However, preliminary work indicates that intensifying systems import entropy while the net lateral balance for mature systems is close to zero.

Raymond and graduate student Michael Herman have published an initial paper on the question of causality in frictional convergence. Further work is underway to extend this work, which may be important in understanding the boundary layers of developing tropical cyclones.

RESULTS

In last year's annual report we outlined the following sequence of events for tropical cyclogenesis:

- Normal tropical conditions favor top-heavy convective mass flux profiles.
- Top-heavy mass flux profiles cause spinup of a mid-level vortex.

- A mid-level vortex results in a smaller instability index.
- Smaller instability index promotes convection with a bottom-heavy mass flux profile.
- Bottom-heavy convection promotes low-level spinup and tropical cyclogenesis.
- Cloud-resolving model results support the relationship between instability index and mass flux profile.

The analysis of a much larger sample of potential cyclogenesis cases supports this picture.

Our theoretical analysis of causality in frictional convergence raises questions about the dynamics of tropical cyclones that need to be addressed.

IMPACT/APPLICATIONS

If the above sequence of events for tropical cyclogenesis withstands scrutiny, then it will provide a useful conceptual framework for forecasting cyclogenesis.

Many of the lessons learned in this work have broader applicability to tropical convection in general. The knowledge generated should help in the effort to constrain the behavior of convective parameterizations in global models, thus enhancing the ability of these models to forecast tropical weather.

RELATED PROJECTS

The current project is related to work being pursued under a grant from the National Science Foundation entitled "Cumulus Convection and Large-Scale Tropical Flows". The purpose of that NSF grant is to refine and extend our understanding of the thermodynamic control of convection and to begin to apply these results to a broader range of tropical disturbances. In addition to the Madden-Julian oscillation, we are particularly interested in equatorial Kelvin waves, tropical easterly waves, and the developmental stages of tropical cyclones. TCS-08 results will advance the purposes of this grant and expertise developed under this and previous NSF support will benefit our Office of Naval Research project as well. Graduate student Michael Herman is supported by by this grant.

We also have NSF support for our role in the PREDICT project with a grant entitled "Vorticity and Thermodynamic Budgets in Easterly Waves – PREDICT Participation". The field program for PREDICT concluded two years ago after obtaining extensive dropsonde data on a number of pre-tropical-depression disturbances as well as a number of non-developing systems. Results from this project complement and strengthen our TCS-08 results. Saška Gjorgjievska is supported by this project.

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